PETROGRAPHIC ANALYSIS OF NORTHERN INDIANA CARBONATE AGGREGATES

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ABSTRACT

A study was made to determine those petrographic parameters that are correlative with carbonate-aggregate quality as indicated by the Los Angeles abrasion and absorption tests. Samples collected at 28 sites in northern and eastern Indiana were analyzed petrographically, chiefly for void content, grain size, grain-size variation, grain shape, and grain interlock.

Most of the sampled sites are in the belt of Silurian rocks of east-central and northwestern Indiana. Though a few sites lie outside this belt, most of these have only a thin Devonian section above the Silurian. Three sites are non-Silurian and are included for comparison.

Most of the samples studied are from Middle and Upper Silurian units. Both biohermal and nonbiohermal facies are included. The biohermal rocks are typically dense but vugular, finely crystalline granular dolomite. Nonbiohermal facies are porous, medium to coarsely crystalline, granular dolomite with dolomite rhombs.

The Los Angeles abrasion losses ranged from 20 to 46 per cent, the rocks in the eastern

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part of the state showing the higher values. Absorption tests indicate the same general quality trend.

Comparison of petrographic studies with Los Angeles abrasion- and absorption-test results indicate the following correlations. (1) As per cent of voids increases, quality decreases. (2) As average grain size increases, quality decreases. (3) Variations from mean grain size appear to have no effect on the quality. (4) As angularity and roughness of the grains increase, quality increases. (5) As grain-to-grain interlock increases, quality increases. Variations in the calcium-magnesium ratio have no apparent effect on aggregate quality, except as they affect the texture.

INTRODUCTION

Carbonate rocks are a major source of mineral aggregates in the United States, especially in the midwestern states. The quality of these aggregates is of prime concern to both the producer and the user.

"Quality" as applied to mineral aggregates is a nebulous term, because it has been used and defined indiscriminately over the years. Any use of it without descriptive qualifiers is meaningless. To say that a particular rock is of high quality is not sufficient, because mineral aggregates are used in many ways and their performance with different usages may vary widely. Therefore, a statement concerning quality must include the intended use.

Mather (1958) describes aggregate quality in terms of grading, physical conditions and properties, and resistance to freezing and thawing; and he emphasizes that quality requirements may properly be different for different uses at different places at the same time. Woods et al. (1958) indicates that the quality of concrete aggregates is dependent upon their serviceability in concrete. In essence, therefore, mineral-aggregate quality is dependent upon its intended use and its satisfactory performance in this use. Whether a material satisfactorily serves this intended purpose or not depends upon its properties. Thus, the properties of a rock determine its quality for a particular use.

Laboratory tests have been developed as aids in evaluating aggregate quality for different uses. Many of the routine laboratory tests were developed for a particular use, but have since been adopted as a general quality rating for many aggregate uses. These tests are empirical in nature. Only a moderate amount of research has been done on the aggregate properties evaluated by these tests, or how these properties influence, if they do, the performance of the aggregate in any particular use. The fact that, many times, the results of routine laboratory tests have not been in accord with actual aggregate performance in the field indicates that more study is needed in defining those properties that influence the field and laboratory performance of a rock to be used as an aggregate. Notable examples of this type of aggregate, aggregate that meets A.S.T.M. tests, are described by Swenson (1957) and by Smith (1963).

In the present study, the authors have attempted to define, petrographically, those properties of carbonate rocks that influence their aggregate quality, as indicated by the Los Angeles abrasion tests and subordinately by absorption tests. This has been a limited, pilot investigation. It has served as a basis for the more complete study on the petrographic analysis of aggregates that is presently being conducted at Purdue University. Some of the preliminary findings of the latter study have been described in an unpublished report (West et al., 1964).

The Los Angeles abrasion test is one of the most popular and widely used laboratory tests. Developed in the mid-thirties as a quality-control test for road aggregate, it is a tumbler-type of test that has been empirically correlated with most types of aggregate uses. It has not always been successful in its evaluation of some rock types for all uses, but its successes far outweigh its failures, especially in the midwest carbonate region.

In the Los Angeles test, the aggregates undergo abrasion, impact, and possibly fatigue stresses. The relative percent of breakdown caused by each of these factors is not known. Effects of individual factors probably change as the test continues, owing to the decrease in particle size. Only the effect of the combination of these factors will be considered in this paper.

Thin-section and polished-section analysis were the principal methods used to investigate properties of the aggregate material. Results of this analysis were then compared with the Los Angeles test results. Petrographic analysis has been employed successfully in the past, particularly with reference to the suitability

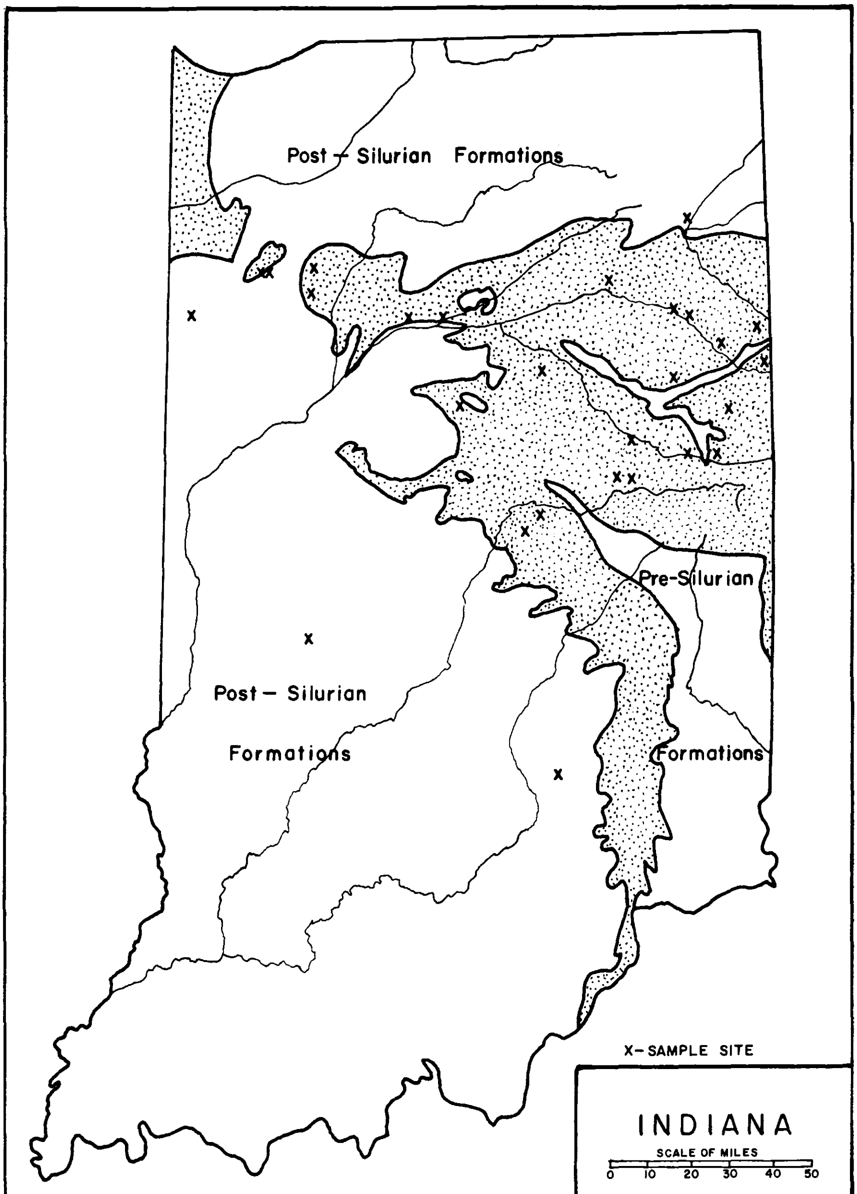

FIGURE 1. Silurian Outcrop Pattern and Sample Location Map, modified from Pinsak and Shaver (1964).

of an aggregate source for concrete. A good summary of the work that was done is given by Lounsbury and Schuster (1964).

Carbonate-rock samples for the present study were collected at 28 sites in northern Indiana, and petrographic analysis and Los Angeles abrasion tests were performed on the samples. The samples taken from each site were a random composite of the stratigraphic units exposed, designated by highway engineers as production samples, in contrast to specific horizon or ledge samples. However, the general stratigraphy of each site was noted and was compared with data from the Indiana Geological Survey (McGregor, 1956, 1963). Figure 1 shows the location of sample sites, and the known outcrops of Silurian formations in Indiana.

STRATIGRAPHY

The rock units from which samples were obtained range in geologic age from Silurian through Mississippian, but most of the specimens were collected from Middle and Upper Silurian units. The majority of the sites sampled are entirely in Silurian rock and at most other sites there is only a thin Devonian cover. Only three sites are entirely outside the area of Silurian outcrops, and these were included for purposes of general comparison.

The Silurian stratigraphy of northern Indiana has been recently revised by the Indiana Geological Survey (Pinsak and Shaver, 1964). A brief discussion of this new and superior stratigraphy is included in this paper, because most of the aggregate samples for this study were obtained from those units which were most revised.

An examination of the generalized stratigraphic section of the Silurian and Devonian of northern Indiana, proposed by Pinsak and Shaver (1964) (fig. 2), reveals that the Huntington dolomite, previously considered to occur stratigraphically between the Kokomo and the Liston Creek Formations, is in fact a biohermal facies of the Niagaran, and possibly of the Lower Cayugan series. Some units, now named the Salamonie Dolomite, that were considered to be the non-reef facies of the Huntington Dolomite in Jay and Randolph Counties, east-central Indiana, have been found to be stratigraphically much older than the typical Huntington reef rocks, found along the Wabash River from Delphi to Fort Wayne. These biohermal structures form bedrock highs, or "klintars," which often project through the glacial drift.

The Silurian units most used as aggregate sources have the following general textures, although many variations occur. The reef or biohermal rocks are typically aphanitic but vugular, to finely crystalline granular dolomite (fig. 3). Most commonly the nonbiohermal facies, especially in east-central Indiana, is porous, medium to coarsely crystalline, granular dolomite with dolomite rhombs (fig. 4). Although other textures occur, these are the most common.

LOS ANGELES ABRASION TEST FINDINGS

Aggregates in the western part of northern Indiana are generally considered to be of higher quality for highway use than those in the east. This view is based chiefly on actual performance records and on the results of Los Angeles abrasion testing. Figure 5 shows an areal plot of per cent of loss in Los Angeles abrasion at the sites investigated. A general trend is apparent in the variation of these values. The rocks in the west show a lower Los Angeles per cent loss than those in the east, though there are exceptions. The range is from 20 per cent abrasion loss near the western border to 46 per cent near the eastern border of the state. Results on certain ledge samples show an even greater range (18 to 55 per cent). A similar plot of average absorption values shows the same general trend.

PETROGRAPHIC STUDIES

By petrographic analysis of thin sections, various parameters indicative of rock properties were evaluated, and the results compared with laboratory or

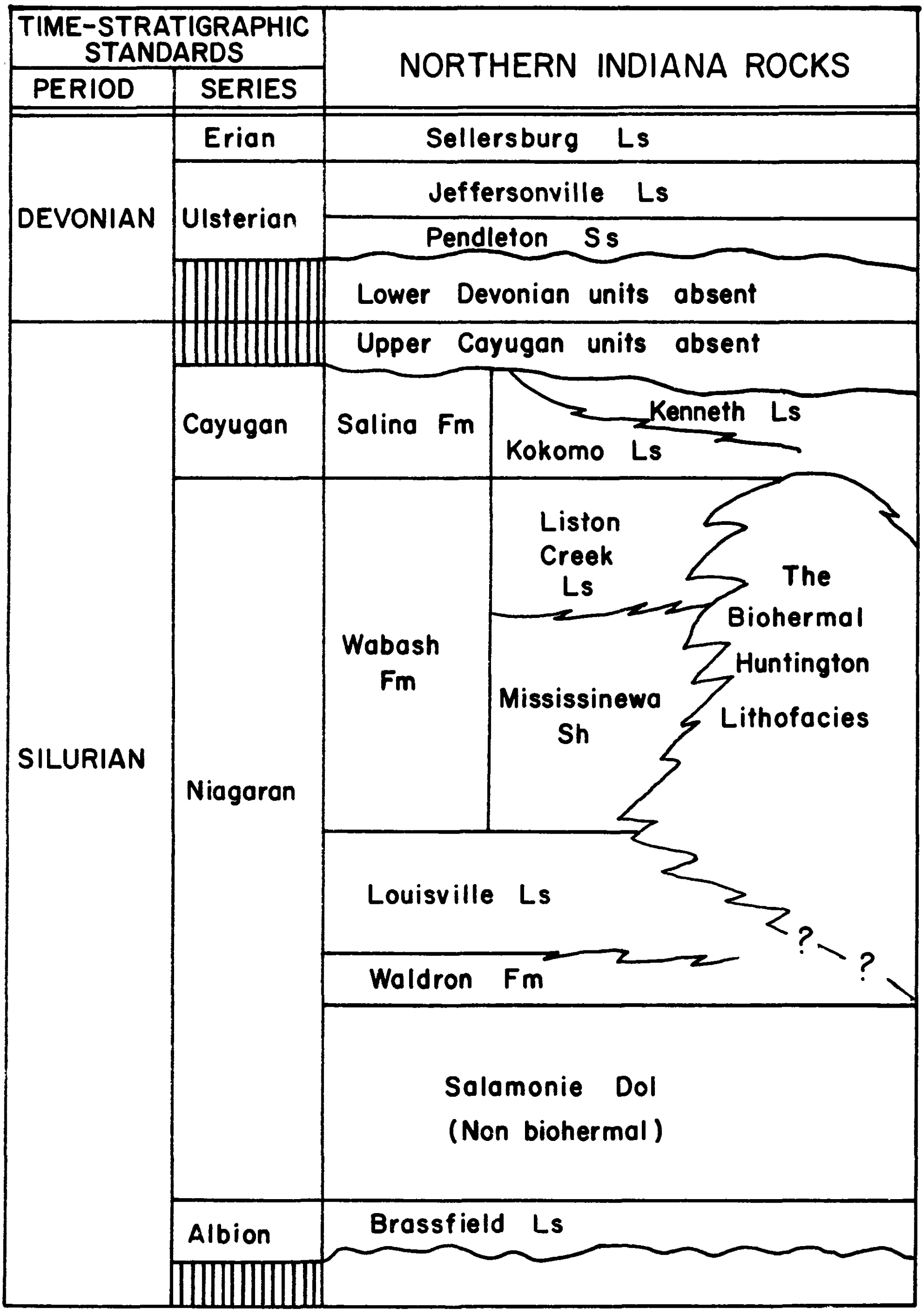

FIGURE 2. Silurian-Middle Devonian Stratigraphy for Northern Indiana, modified from Pinsak and Shaver (1964).

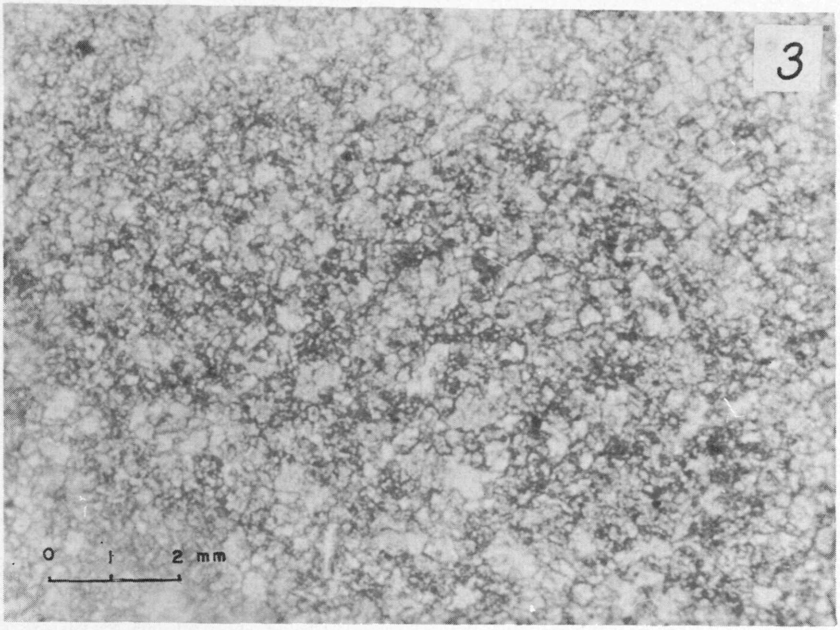

FIGURE 3. Photomicrograph of the texture of a typical biohermal rock.

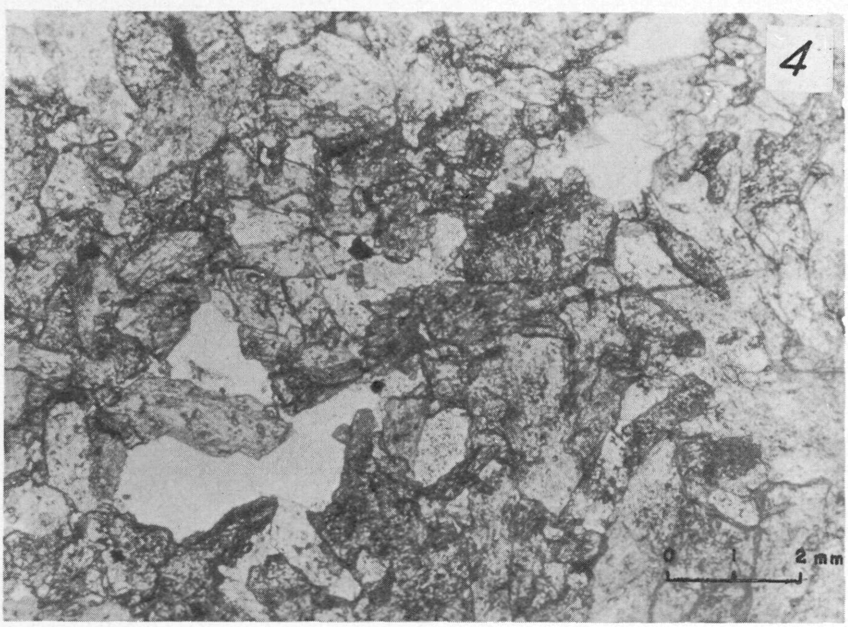

FIGURE 4. Photomicrograph of a common nonbiohermal dolomite.

field test results. The parameters studied, for comparison with the Los Angeles abrasion test results, were (1) percentage of voids, (2) average (bulk) grain or crystal size, (3) amount of grain-size variation from the average size, (4) angularity or roughness of the grains, and (5) grain-to-grain interlock. The terms grain and crystal are used interchangeably in this paper, because most of the individual grains in these rocks are carbonate crystals.

Because limited chemical analyses, in the form of CaO and MgO composition,

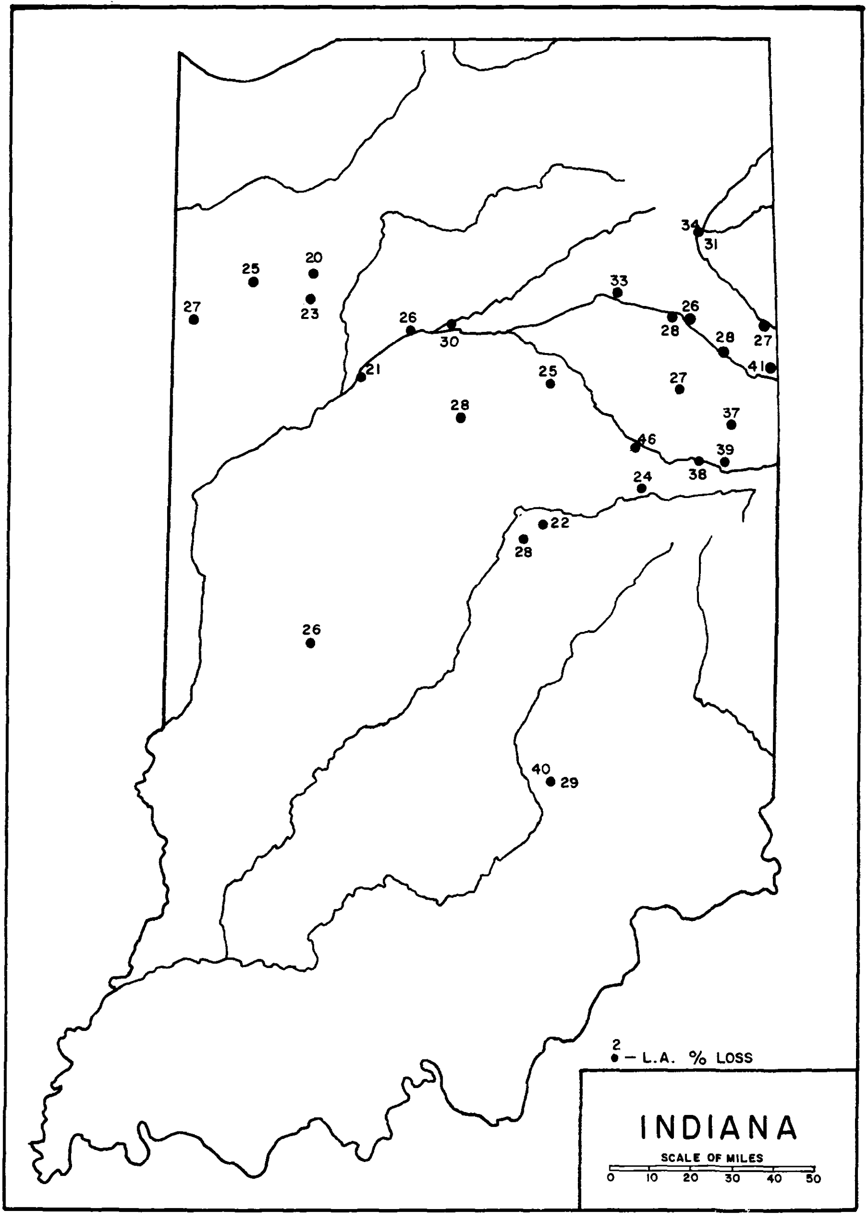

FIGURE 5. Geographic Variation of the average Los Angeles Abrasion Value.

were available for most of the samples, this information was also compared to the Los Angeles abrasion results. The purpose was to see whether or not the parameters being measured had any significant relation to the aggregate's resistance in the Los Angeles test.

The value for void percentage was estimated. It was checked by linear traverses under a microscope, and indirectly by absorption tests. After several weeks of petrographic evaluation of this parameter, the authors were able to estimate this value to within two percent. The greatest source of error in evaluating voids in thin section came from the artificial voids created by particle plucking during the grinding process, though a skilled petrographer can usually identify such features. The size, shape, and interconnection of the voids are probably parameters worthy of study as factors influencing aggregate quality for all general uses, but they were not included in this study. Both the average grain size and the grain-size variation were estimated by a microscale within the optical system. Angularity, or particle roughness, was estimated by the variation in shape of the particle from that of a sphere. Grain-to-grain interlock was also estimated, using arbitrary criteria set up by the authors.

RESULTS AND SUMMARY

A comparison of the petrographic data with the Los Angeles abrasion and absorption test results indicates the following relationships:

1. Quality decreases as the percentage of voids increases.
2. Quality decreases as the average (bulk) grain size increases.
3. Variations from the mean grain size seem to have no effect on the quality.
4. Quality increases with an increase in the angularity or roughness of the grains.
5. Quality increases as the grain-to-grain interlock increases.
6. Variations in the calcium-magnesium ratio seem to have no effect on the quality, except as they affect the texture.

Any material is strongest when it occurs in a single homogeneous, continuous mass. Any discontinuities or imperfections in the form of voids should cause a strength reduction, because of stress concentrations around these voids. It was believed, prior to the study, that a variation in the amount of voids in a rock would have a significant influence on its performance, both in the laboratory and in the field. This was substantiated by a comparison of the percentage of voids and the Los Angeles results. Those aggregates with the highest percent loss in the Los Angeles test also had more voids by volume. Exceptions existed, but the number of pieces studied for these sites were probably not statistically significant, so that atypical rather than average pieces may have dominated. Aggregates with a Los Angeles abrasion loss of less than 30 per cent had an average porosity of 6 per cent; for those rocks with Los Angeles losses above 30 per cent, the average porosity was 16 per cent.

Voids in carbonate aggregates can be classified in two broad catagories, solution cavities and inherent pores. By inherent pores, the authors mean those voids created during lithification and dolomitization. Inherent pores are small, usually discontinuous, and are distinctly a part of the texture. Much of the porosity developed in some dolomites is of this type. Solution voids, on the other hand, are larger and interconnected, and they truncate textural trends. Solution voids mark lines and planes of weakness along which fracture may occur. Inherent pores influence the aggregate strength in a more subtle way. They probably help control fracture surfaces, but possibly they contribute more to the abrasion and crushing resistance of the rock.

The average grain or crystal size shows a perceptible relationship to the Los Angeles results. The actual importance is hard to estimate from the present study, because this property is closely associated with grain shape and the amount of their interlock. It was found that the coarser the average grain size, the higher the Los Angeles loss; however, it must be remembered that grain sizes for most of the rocks included in this study were very small. Possibly a wider range of grain sizes would not show such a distinctive trend. Thus, this parameter should be explored more fully.

Variations from the average grain size showed no noticeable trends, although wide variations from the bulk or average sizes were observed. From these findings, it seems that only the average grain size is a significant factor in strength quality.

Grain interlock, of all of the parameters investigated, showed the best correlation with Los Angeles loss variations. The better the grain-to-grain interlock, the lower the Los Angeles per cent loss. Grain interlock was evaluated as the degree of difficulty in moving one particle past adjacent particles. As noted earlier, the criteria used by the authors were arbitrary textural features. Grain-to-grain interlock is related to grain shape. Usually, as the crystals or grains become more angular and irregular, interlock becomes better. There were some exceptions, but these two features possibly could be evaluated as a single parameter.

The ratio of calcium to magnesium in the aggregates gave no distinct trends when plotted against the Los Angeles percent-loss values. There seemed to be some minor effects of this property on the overall quality. As the mineralogy approached a more ideal dolomite, there were definite textural changes in the rock. This effect needs to be explored further.

In summary, various petrographic parameters of carbonate rocks were compared with the Los Angeles abrasion test and absorption data, Some of the parameters investigated seemed to have no significant relation to the performance of aggregates in the Los Angeles tests. Others showed moderate to good trends. The rock properties or parameters that were investigated indicate that petrographic analysis offers a positive approach to correlating rock properties, laboratory tests, and field performance of carbonate aggregates. Every possible correlation is needed in order to evaluate aggregate quality for better utilization of carbonate rocks for engineering purposes.

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